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Flavor Symmetry, K^0-$\bar{K}^0$ Mixing and New Physics Effects on CP Violation in $D^\pm$ and $D_s^\pm$ Decays

Harry J. Lipkin [1]
Department of Particle Physics, Weizmann Institute of Science, Rehovot 76100, Israel
School of Physics and Astronomy, Raymond and Beverly Sackler Faculty of Exact Sciences, Tel Aviv University, Tel Aviv, Israel

Zhi-zhong Xing [2]
Sektion Physik, Universität München, Theresienstrasse 37A, 80333 München, Germany

Abstract

Flavor symmetry and symmetry breaking, K^0-$\bar{K}^0$ mixing and possible effects of new physics on CP violation in weak decay modes $D^\pm \rightarrow K_{\rm S,L} + X^\pm$, $(K_{\rm S,L} + \pi^0)_{K^*} + X^\pm$ (for $X = \pi, \rho, a_1$) and $D_s^\pm \rightarrow K_{\rm S,L} + X_s^\pm$, $(K_{\rm S,L} + \pi^0)_{K^*} + X_s^\pm$ (for $X_s = K, K^*$) are analyzed. Relations between $D^\pm$ and $D_s^\pm$ decay branching ratios are obtained from the $d \Leftrightarrow s$ subgroup of SU(3) and dominant symmetry-breaking mechanisms are investigated. A CP asymmetry of magnitude 3.3×10^{-3} is shown to result in the standard model from K^0-$\bar{K}^0$ mixing in the final-state. New physics affecting the doubly Cabibbo-suppressed channels might either cancel this asymmetry or enhance it up to the percent level. A comparison between the CP asymmetries in $D^\pm_{(s)} \rightarrow K_{\rm S} X^\pm_{(s)}$ and $D^\pm_{(s)} \rightarrow K_{\rm L} X^\pm_{(s)}$ can pin down effects of new physics.

[1]Electronic address: ftlipkin@wiswic.weizmann.ac.il
[2]Electronic address: xing@hep.physik.uni-muenchen.de

Effects of CP violation in weak decays of D mesons are expected to be rather small, of order 10^{-3} or lower, within the standard electroweak model [1]. They can naturally be enhanced up to the $O(10^{-2})$ level, if new physics beyond the standard model exists in the charm-quark sector [2, 3]. Although no new physics model suggests direct CP violation in charged D-meson decays, a search is cheap and easy when decays of charge-conjugate particles are measured [4]. Some efforts have so far been made to search for CP violation in the D system [5]. The experimental prospects are becoming brighter, with the development of higher-luminosity e^+e^- colliders and hadron machines [6, 7].

While a variety of mixing and CP-violating phenomena may manifest themselves in neutral D-meson decays [8], the charged D-meson transitions provide a unique experimental opportunity for the study of direct CP violation [6, 9]. Some phenomenological analyses of CP asymmetries in charged D-meson decay modes have been made (see, e.g., Ref. [1, 4] and Refs. [10] – [12]). In particular, the importance and prospects of searching for CP-violating new physics in the promising decays $D^\pm \rightarrow K_{\rm S}X^\pm$ and $D^\pm \rightarrow K_{\rm S}K_{\rm S}K^\pm$, where $X^\pm$ denotes any charged hadronic state, have been outlined in Ref. [4].

In the present note we first consider flavor-symmetry relations between corresponding $D^\pm$ and $D^\pm_s$ and then discuss both the non-negligible K^0-$\bar{K}^0$ mixing effect and the possible (significant) new physics effect on CP asymmetries in

$$D^\pm \;\rightarrow\; K_{\rm S,L} \;+\; X^\pm \tag{1a}$$

(for $X = \pi, \rho, a_1$) and

$$D^\pm_s \;\rightarrow\; K_{\rm S,L} \;+\; X^\pm_s \tag{1b}$$

(for $X_s = K, K^*$) decays. The similar decay modes involving the resonance K^{*0} or $\bar{K}^{*0}$, i.e.,

$$D^\pm \;\rightarrow\; \left(K_{\rm S,L} + \pi^0\right)_{K^*} \;+\; X^\pm \tag{2a}$$

and

$$D^\pm_s \;\rightarrow\; \left(K_{S,L} + \pi^0\right)_{K^*} \;+\; X^\pm_s \tag{2b}$$

are also considered. Within the standard model we show that CP violation in these processes comes mainly from K^0-$\bar{K}^0$ mixing and may lead to a decay rate asymmetry of magnitude 3.3×10^{-3}. Beyond the standard model the CP asymmetries are possible to reach the percent level due to the enhancement from new physics. A comparison between the CP asymmetries in $D^\pm_{(s)} \rightarrow K_{\rm S}X^\pm_{(s)}$ and $D^\pm_{(s)} \rightarrow K_{\rm L}X^\pm_{(s)}$ decays may pin down the involved new physics.

Within the standard electroweak model the transitions in Eqs. (1) and (2) can occur through both the Cabibbo-allowed channels (Fig. 1) and the doubly Cabibbo-suppressed channels (Fig. 2). The penguin $c \rightarrow u$ transition cannot contribute to these decays. The eight diagrams in Figs. 1 and 2 describe all the diagrams allowed by QCD and the standard electroweak model if the quark lines are allowed to go backward and forward in time, and arbitrary numbers of gluon exchanges are included [13].

Each of the four diagrams in Fig. 1 is seen to go into one of the diagrams of Fig. 2 under the $d \Leftrightarrow s$ transformation which interchanges d and s flavors and is included in SU(3). Its use with the flavor topology of Figs. 1 and 2 not only gives SU(3) symmetry relations but also pinpoints the dominant sources of symmetry breaking. We first note some relations between pairs of amplitudes related by the $d \Leftrightarrow s$ transformation:

$$\frac{|A(D^+ \to K^{(*)0} X^+)|}{|A(D_s^+ \to \bar{K}^{(*)0} X_s^+)|} = \frac{|V_{cd} V_{us}^*|}{|V_{cs} V_{ud}^*|} = \frac{|A(D_s^+ \to K^{(*)0} X_s^+)|}{|A(D^+ \to \bar{K}^{(*)0} X^+)|} \ , \tag{3}$$

where V_{ij} (for $i = u, c$ and $j = d, s$) are the Cabibbo-Kobayashi-Maskawa (CKM) matrix elements. The explicit assumptions needed to derive these relations are:

1. d and s quarks couple equally to gluons at all stages of these diagrams, including final state interactions.

2. The properties of the weak interactions under the $d \Leftrightarrow s$ transformation are given by the CKM matrix elements.

That d and s quarks couple equally to gluons at short distances in all the complicated quark diagrams seems reasonable. Thus further $d \Leftrightarrow s$ symmetry breaking occurs only at the hadron level via decay constants and form factors. The $d \Leftrightarrow s$ transformation changes pions into kaons, ρ's into K^*'s, etc. The breaking produced by the corresponding changes in masses, decay constants and form factors must be taken into account. The form factors depend upon whether the $q\bar{q}$ pair is pointlike or has a hadronic scale defined by the initial state wave function or pair creation by gluons.

Branching ratio data for these decays may well become available with sufficient precision to test SU(3) symmetry and symmetry breaking before they have sufficient precision to show CP violation or new physics. They can therefore provide useful constraints on parameters and relative strengths of different diagrams to help narrow the searches for crucial effects predicted by new physics.

We now investigate the phases relevant to CP violation. For each decay mode under discussion, its doubly Cabibbo-suppressed transition amplitude and its Cabibbo-allowed one may have different weak and strong phases. We denote the ratio of two transition amplitudes for $D^+ \to K^{(*)0} X^+$ and $\bar{K}^{(*)0} X^+$ or $D_s^+ \to K^{(*)0} X^+$ and $\bar{K}^{(*)0} X^+$ (before K^0-$\bar{K}^0$ mixing) as follows:

$$\begin{aligned} \frac{A(D^+ \to K^{(*)0} X^+)}{A(D^+ \to \bar{K}^{(*)0} X^+)} &= R_d e^{\mathrm{i}\delta_d} \frac{V_{cd} V_{us}^*}{V_{cs} V_{ud}^*} \ , \\ \frac{A(D_s^+ \to K^{(*)0} X_s^+)}{A(D_s^+ \to \bar{K}^{(*)0} X_s^+)} &= R_s e^{\mathrm{i}\delta_s} \frac{V_{cd} V_{us}^*}{V_{cs} V_{ud}^*} \ , \end{aligned} \tag{4}$$

where δ_q and R_q (for $q = d$ or s) denote the strong phase difference and the ratio of real hadronic matrix elements, respectively. Under $d \Leftrightarrow s$ symmetry, $\delta_s = -\delta_d$ and $R_s = R_d^{-1}$.

The magnitudes of R_d and R_s can be estimated with the help of the effective weak Hamiltonian and the naive factorization approximation. Neglecting the annihilation diagrams in Figs. 1 and 2, which are expected to have significant form factor suppression, we arrive at

$$\begin{aligned}
\frac{1}{R_d} &= 1 + \frac{a_1}{a_2} \cdot \frac{\langle X^+|(\bar{u}d)_{V-A}|0\rangle\langle \bar{K}^{(*)0}|(\bar{s}c)_{V-A}|D^+\rangle}{\langle K^{(*)0}|(\bar{d}s)_{V-A}|0\rangle\langle X^+|(\bar{u}c)_{V-A}|D^+\rangle} , \\
R_s &= 1 + \frac{a_1}{a_2} \cdot \frac{\langle X^+_s|(\bar{u}s)_{V-A}|0\rangle\langle K^{(*)0}|(\bar{d}c)_{V-A}|D^+_s\rangle}{\langle \bar{K}^{(*)0}|(\bar{d}s)_{V-A}|0\rangle\langle X^+_s|(\bar{u}c)_{V-A}|D^+_s\rangle} ,
\end{aligned} \tag{5}$$

where $a_1 \approx 1.1$ and $a_2 \approx -0.5$ are the effective Wilson coefficients at the $O(m_c)$ scale [14]. We list the explicit results of R_d and R_s in Table 1, in which the relevant decay constants and form factors are self-explanatory and their values can be found from Refs. [15, 16].

These expressions show clearly that the relation $R_s = R_d^{-1}$ is violated only by the obvious $d \Leftrightarrow s$ breaking in the decay constants and form factors, and holds in the limit where these decay constants and form factors have the same values for all pairs related by $d \Leftrightarrow s$; e.g. $m_\pi = m_K$, $f_\pi = f_K$, $F_0^{DK}(m_\pi^2) = F_0^{DK}(m_K^2)$, $m_\rho = m_{K^*}$, $f_\rho = f_{K^*}$, $F_1^{DK}(m_\rho^2) = F_1^{D_sK}(m_{K^*}^2)$, etc.

The diagrams selected by factorization differ from other diagrams only in the form factors. Thus relaxing the demand for factorization can only introduce additional form factors and decay constants into the expressions in Table 1 corresponding to the replacement of color-favored couplings by color suppressed couplings.

The ballpark numbers obtained in Table 1 serve only for illustration and show that the $d \Leftrightarrow s$ symmetry between R_s and R_d^{-1} is reasonably acceptable for either the two-pseudoscalar states or the pseudoscalar-vector (axialvector) states. In general $|R_d| \sim O(1)$ and $|R_s| \sim O(1)$ are expected to be true, independent of the dynamical details of these transitions.

We now consider the decays into final-states including $K_{\rm S}$ or $K_{\rm L}$, where the dominant CP violation in the standard model comes from the K^0-$\bar{K}^0$ mixing described by

$$\begin{aligned}
|K_{\rm S}\rangle &= p|K^0\rangle + q|\bar{K}^0\rangle , \\
|K_{\rm L}\rangle &= p|K^0\rangle - q|\bar{K}^0\rangle ,
\end{aligned} \tag{6}$$

where p and q are complex parameters. To ensure the rephasing invariance of all analytical results, we do not use the popular notation $q/p = (1-\epsilon)/(1+\epsilon)$. As we shall see later on, the mixing-induced CP violation

$$\delta_K = \frac{|p|^2 - |q|^2}{|p|^2 + |q|^2} \approx 3.3 \times 10^{-3} , \tag{7}$$

which has been measured in semileptonic $K_{\rm L}$ decays [15], may play a significant role in the CP asymmetries of $D^\pm$ and $D_s^\pm$ decays.

The ratios of transition amplitudes for D^- and D_s^- decays can be read off from Eq. (4) with the complex conjugation of relevant quark mixing matrix elements. Then we obtain [3]

$$\frac{A(D^+ \rightarrow K_{\rm S} X^+)}{A(D^- \rightarrow K_{\rm S} X^-)} = \frac{(V_{cs}V^*_{ud})q^* \ + \ R_d e^{{\rm i}\delta_d}(V_{cd}V^*_{us})p^*}{(V^*_{cs}V_{ud})p^* \ + \ R_d e^{{\rm i}\delta_d}(V^*_{cd}V_{us})q^*} \ ,$$

$$\frac{A(D_s^+ \rightarrow K_{\rm S} X_s^+)}{A(D_s^- \rightarrow K_{\rm S} X_s^-)} = \frac{(V_{cs}V^*_{ud})q^* \ + \ R_s e^{{\rm i}\delta_s}(V_{cd}V^*_{us})p^*}{(V^*_{cs}V_{ud})p^* \ + \ R_s e^{{\rm i}\delta_s}(V^*_{cd}V_{us})q^*} \ . \tag{8}$$

Although q/p itself depends on the phase convention of $|K^0\rangle$ and $|\bar{K}^0\rangle$ meson states, which relies intrinsically on that of relevant quark fields [17], the following two quantities are rephasing-invariant:

$$\frac{V_{cd}V^*_{us}}{V_{cs}V^*_{ud}} \cdot \frac{p^*}{q^*} = re^{+{\rm i}\phi} \ , \qquad \frac{V^*_{cd}V_{us}}{V^*_{cs}V_{ud}} \cdot \frac{q^*}{p^*} = \bar{r}e^{-{\rm i}\phi} \ . \tag{9}$$

Note that $|q/p|$ deviates from unity only at the $O(10^{-3})$ level, i.e., the order of observable CP violation in K^0-$\bar{K}^0$ mixing [15]. Therefore $r = \bar{r} = \tan^2\theta_{\rm C} \approx 5\%$ is an excellent approximation, where $\theta_{\rm C} \approx 13^\circ$ is the Cabibbo angle. The CP asymmetries of $D^\pm \rightarrow K_{\rm S}X^\pm$ and $D_s^\pm \rightarrow K_{\rm S}X_s^\pm$ transitions can then be given as

$$\begin{aligned} \mathcal{A}_d &= \frac{|A(D^- \rightarrow K_{\rm S}X^-)|^2 - |A(D^+ \rightarrow K_{\rm S}X^+)|^2}{|A(D^- \rightarrow K_{\rm S}X^-)|^2 + |A(D^+ \rightarrow K_{\rm S}X^+)|^2} \\ &\approx \delta_K \ + \ 2R_d \tan^2\theta_{\rm C} \sin\phi \sin\delta_d \ , \end{aligned} \tag{10}$$

and

$$\begin{aligned} \mathcal{A}_s &= \frac{|A(D_s^- \rightarrow K_{\rm S}X_s^-)|^2 - |A(D_s^+ \rightarrow K_{\rm S}X_s^+)|^2}{|A(D_s^- \rightarrow K_{\rm S}X_s^-)|^2 + |A(D_s^+ \rightarrow K_{\rm S}X_s^+)|^2} \\ &\approx \delta_K \ + \ 2R_s \tan^2\theta_{\rm C} \sin\phi \sin\delta_s \ , \end{aligned} \tag{11}$$

where δ_K has been given in Eq. (7). Clearly $\mathcal{A}_d$ or $\mathcal{A}_s$ consists of two different contributions: that from K^0-$\bar{K}^0$ mixing in the final state, and that from the interference between Cabibbo-allowed and doubly Cabibbo-suppressed channels.

The smallness of δ_K implies that the K^0-$\bar{K}^0$ mixing phase is nearly the same as that in direct decays of K^0 and $\bar{K}^0$ mesons [18]. Thus one may take $q/p = (V_{us}V^*_{ud})/(V^*_{us}V_{ud})$ in the leading-order approximation. The rephasing-invariant weak phase ϕ turns out to be the largest outer angle of the unitarity triangle $V_{cd}V^*_{ud} + V_{cs}V^*_{us} + V_{cb}V^*_{ub} = 0$ (see, e.g., Ref. [19]) and its magnitude can roughly be constrained as follows:

$$\phi = \arg\left(\frac{V_{cd}V^*_{ud}}{V_{cs}V^*_{us}}\right) \geq \pi \ - \ \arctan\left|\frac{V_{cb}V^*_{ub}}{V_{cd}V^*_{ud}}\right| \ . \tag{12}$$

[3]The formulas for the decays involving $K^{*0} \rightarrow K^0\pi^0 \rightarrow K_{\rm S}\pi^0$ and $\bar{K}^{*0} \rightarrow \bar{K}^0\pi^0 \rightarrow K_{\rm S}\pi^0$ are basically the same as those for $D^\pm \rightarrow K_{\rm S}X^\pm$ or $D_s^\pm \rightarrow K_{\rm S}X_s^\pm$ transitions, therefore they will not be written down for simplicity.

In obtaining this bound, we have taken $|V_{cd}V_{ud}^*| \approx |V_{cs}V_{us}^*| \gg |V_{cb}V_{ub}^*|$ into account. We find $\sin\phi \sim O(\leq 10^{-3})$ by use of current experimental data on quark flavor mixing [15]. This result, together with $|R_q| \sim O(1)$ and $\tan^2\theta_{\rm C} \approx 5\%$, implies that the CP asymmetry arising from the interference between Cabibbo-allowed and doubly Cabibbo-suppressed channels is negligibly small in $\mathcal{A}_q$ (for $q = d$ or s). One then concludes that $\mathcal{A}_s \approx \mathcal{A}_d \approx \delta_K$ holds to a good degree of accuracy in the standard model. Such δ_K-induced CP-violating effects can also be observed in the semileptonic $D^\pm$ and $D_s^\pm$ decays which involve $K_{\rm S}$ or $K_{\rm L}$ meson via K^0-$\bar{K}^0$ mixing in the final states [11].

The conclusion drawn above may not be true if new physics enters the decay modes under discussion. As pointed out in Ref. [4], one can wonder about a kind of new physics which causes the decay channels resembling the doubly Cabibbo-suppressed ones in Fig. 2 but occurring through a new charged boson or something more complicated than the W boson. The amplitudes of such new channels may remain to be suppressed in magnitude (e.g., of the same order as the doubly Cabibbo-suppressed amplitudes in the standard model), but they are likely to have significantly different weak and strong phases from the dominant Cabibbo-allowed channels in Fig. 1 and result in new CP-violating asymmetries via the interference effects. The strong phases are expected to be very different because of the presence of meson resonances in the D mass region which affect the phases of the doubly-suppressed $D^\pm$ and Cabibbo-allowed D_s amplitudes while the Cabibbo-allowed $D^\pm$ and doubly-suppressed D_s decays feed exotic channels which have no resonances [13]. Following this illustrative picture of new physics, we modify the ratios of transition amplitudes in Eq. (4) as follows:

$$\begin{aligned} \frac{A(D^+ \rightarrow K^0 X^+)}{A(D^+ \rightarrow \bar{K}^0 X^+)} &= R'_d e^{{\rm i}\delta'_d} \frac{U_{cd}U_{us}^*}{V_{cs}V_{ud}^*} \; , \\ \frac{A(D_s^+ \rightarrow K^0 X_s^+)}{A(D_s^+ \rightarrow \bar{K}^0 X_s^+)} &= R'_s e^{{\rm i}\delta'_s} \frac{U_{cd}U_{us}^*}{V_{cs}V_{ud}^*} \; , \end{aligned} \tag{13}$$

in which δ'_q, $U_{cd}U_{us}^*$ and R'_q (for $q = d$ or s) stand for the effective strong phase difference, the effective weak coupling and the ratio of effective real hadronic matrix elements, respectively. Note that these quantities are composed of both the contribution from doubly Cabibbo-suppressed channels in the standard model and that from additional channels induced by new physics. The same kind of new physics might also affect K^0-$\bar{K}^0$ mixing, but this effect can always be incorporated into the p and q parameters. In this case the rephasing-invariant combinations in Eq. (9) become

$$\frac{U_{cd}U_{us}^*}{V_{cs}V_{ud}^*} \cdot \frac{p^*}{q^*} = r' e^{+{\rm i}\phi'} \; , \qquad \frac{U_{cd}^*U_{us}}{V_{cs}^*V_{ud}} \cdot \frac{q^*}{p^*} = \bar{r}' e^{-{\rm i}\phi'} \; . \tag{14}$$

Here $r' = \bar{r}'$ remains to be a good approximation, but the magnitude of r' (or $\bar{r}'$) may deviate somehow from $\tan^2\theta_{\rm C} \approx 5\%$. The CP asymmetries of $D^\pm \rightarrow K_{\rm S} X^\pm$ and $D_s^\pm \rightarrow K_{\rm S} X_s^\pm$ decays, similar to those obtained in Eqs. (10) and (11), read as

$$\mathcal{A}'_d \;\approx\; \delta_K \;+\; 2R'_d r' \sin\phi' \sin\delta'_d \; ,$$

$$\mathcal{A}'_s \;\approx\; \delta_K \;+\; 2R'_s r' \sin\phi' \sin\delta'_s \; . \qquad (15)$$

If CP violation from the interference between the channel induced by standard physics and that arising from new physics is comparable in magnitude with δ_K (i.e., at the $O(10^{-3})$ level) or dominant over δ_K (i.e., at the $O(10^{-2})$ level), then significant difference between $\mathcal{A}'_s$ and $\mathcal{A}'_d$ should in general appear. This follows that $\delta'_s \neq \delta'_d$ and they may even have the opposite signs. For illustration, we plot the dependence of $\mathcal{A}'_d$ and $\mathcal{A}'_s$ on ϕ' in Fig. 3 with the typical inputs $r' = 0.04$, $R'_d \sin\delta'_d = 0.3$ and $R'_s \sin\delta'_s = -0.5$. Clearly it is worthwhile to measure both asymmetries, and a comparison between them will be helpful to examine SU(3) symmetry and probe possible new physics effects.

The CP-violating asymmetries in $D^\pm \rightarrow K_{\rm L} X^\pm$ and $D^\pm_s \rightarrow K_{\rm L} X^\pm_s$ decays can directly be obtained from those in Eqs. (10), (11) and (15) through the replacements $R_q \rightarrow -R_q$ and $R'_q \rightarrow -R'_q$ (for $q = d$ or s), as ensured by CPT symmetry in the total width [20] . The point is simply that q/p becomes $-q/p$, if one moves from the $K_{\rm S} X^\pm_{(s)}$ state to the $K_{\rm L} X^\pm_{(s)}$ state. The difference between the CP asymmetries in $D^\pm_{(s)} \rightarrow K_{\rm S} X^\pm_{(s)}$ and $D^\pm_{(s)} \rightarrow K_{\rm L} X^\pm_{(s)}$ turns out to be

$$\begin{aligned} \mathcal{A}'_d(K_{\rm S}) \; - \; \mathcal{A}'_d(K_{\rm L}) \;&\approx\; 4R'_d r' \sin\phi' \sin\delta'_d \; , \\ \mathcal{A}'_s(K_{\rm S}) \; - \; \mathcal{A}'_s(K_{\rm L}) \;&\approx\; 4R'_s r' \sin\phi' \sin\delta'_s \; . \end{aligned} \qquad (16)$$

This implies an interesting possibility to pin down the involved new physics, which significantly violates CP invariance. For either $D^\pm$ or $D^\pm_s$ decays, we may explicitly conclude that the CP-violating effect induced by new physics is

- vanishing or negligibly small, if the relationship $\mathcal{A}'_q(K_{\rm S}) \approx \mathcal{A}'_q(K_{\rm L}) \approx \delta_K$ is observed in experiments;
- comparable in magnitude with the δ_K-induced CP violation, if $|\mathcal{A}'_q(K_{\rm S})| \gg |\mathcal{A}'_q(K_{\rm L})|$ (or vice versa) is experimentally detected;
- dominant over the δ_K-induced CP asymmetry, if $\mathcal{A}'_q(K_{\rm S}) \approx -\mathcal{A}'_q(K_{\rm L})$ (of order 10^{-2}) is measured in experiments.

These conclusions are quite general and they should also be valid for other types of new physics involved in the charm-quark sector.

In view of current experimental data [15], the branching ratios of $D^\pm \rightarrow K_{\rm S,L} + (\pi^\pm, \rho^\pm, a^\pm_1)$ are estimated to be about 1.4%, 3.3% and 4.0%, respectively. The branching ratios of $D^\pm_s \rightarrow K_{\rm S,L} + (K^\pm, K^{*\pm})$ amount approximately to 1.8% and 2.2%, respectively [4]. It is therefore

[4]The decay modes involving the $\bar{K}^{*0}$ (or K^{*0}) resonance may have smaller branching ratios, as both $\bar{K}^{*0} \rightarrow \bar{K}^0 \pi^0$ and $\bar{K}^{*0} \rightarrow K^- \pi^+$ are allowed but only the former is relevant to our purpose. For example, the branching ratio of $D^+ \rightarrow (K_{\rm S,L} + \pi^0)_{K^*} + \pi^+$ is expected to be 3.2×10^{-3} from current data [15], about 1/5 of the branching ratio of $D^+ \rightarrow K_{\rm S,L} + \pi^+$.

possible to measure the δ_K-induced CP asymmetries in these decay modes with about 10^{7-8} $D^{\pm}$ or $D_s^{\pm}$ events. If new physics enhances the asymmetries up to the percent level, then clean signals of CP violation can be established with only about 10^6 $D^{\pm}$ or $D_s^{\pm}$ events.

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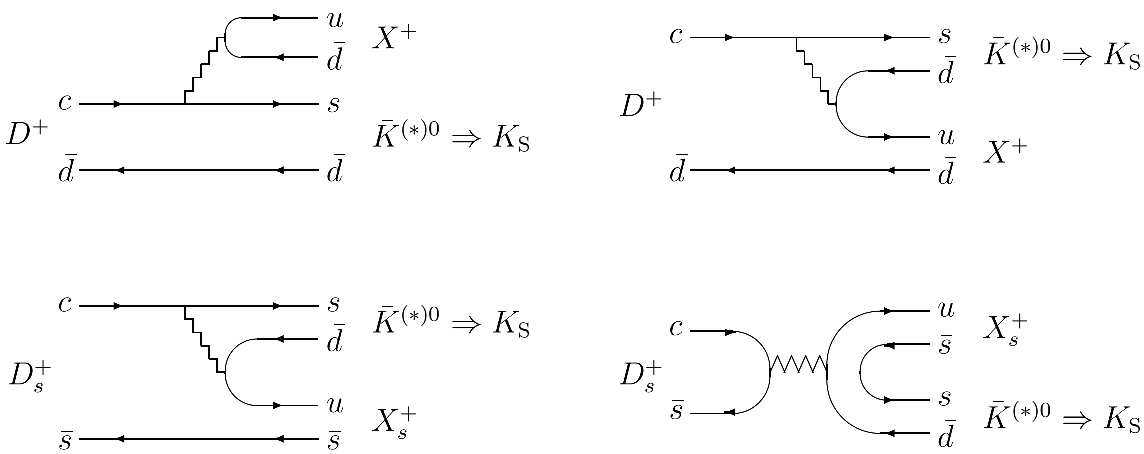

Figure 1: Cabibbo-allowed channels for $D^+ \to K_\mathrm{S}X^+$, $(K_\mathrm{S}\pi^0)_{K^*}X^+$ and $D_s^+ \to K_\mathrm{S}X_s^+$, $(K_\mathrm{S}\pi^0)_{K^*}X_s^+$ decays in the standard model. Here $X = \pi$, ρ or a_1, $X_s = K$ or K^*, and K_S can be replaced by K_L.

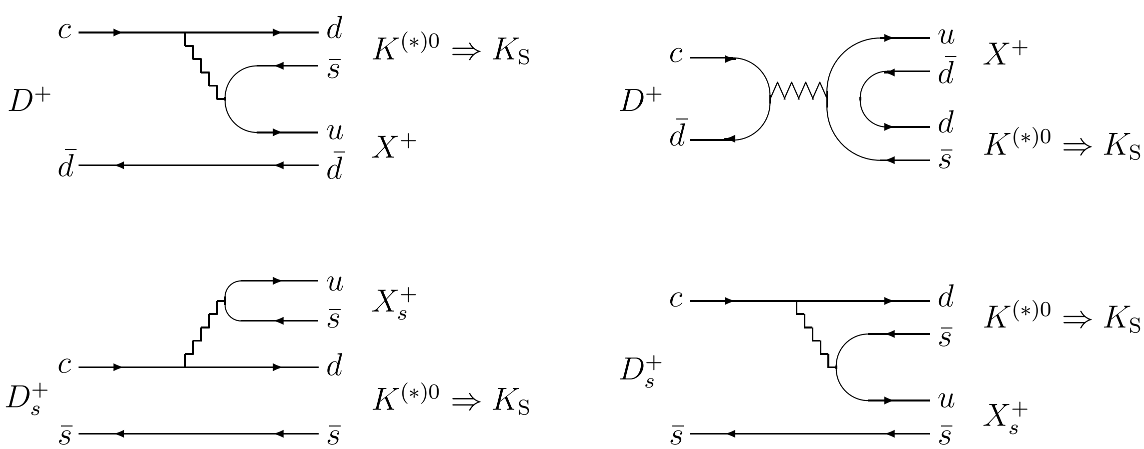

Figure 2: Doubly Cabibbo-suppressed channels for $D^+ \to K_\mathrm{S}X^+$, $(K_\mathrm{S}\pi^0)_{K^*}X^+$ and $D_s^+ \to K_\mathrm{S}X_s^+$, $(K_\mathrm{S}\pi^0)_{K^*}X_s^+$ decays in the standard model. Here $X = \pi$, ρ or a_1, $X_s = K$ or K^*, and K_S can be replaced by K_L.

Table 1: Estimation of R_d and R_s in the naive factorization approximation. Note that the expressions for $D^+ \to K^{*0}\rho^+$ vs $\bar{K}^{*0}\rho^+$ and $K^{*0}a_1^+$ vs $\bar{K}^{*0}a_1^+$ as well as $D_s^+ \to K^{*0}K^{*+}$ vs $\bar{K}^{*0}K^{*+}$ decays are too complicated to be listed here.

D^+ decays	Expression of R_d^{-1}	Value of $\|R_d\|^{-1}$
$K^0\pi^+$ vs $\bar{K}^0\pi^+$	$1 + \frac{a_1}{a_2} \cdot \frac{f_\pi}{f_K} \cdot \frac{F_0^{DK}(m_\pi^2)}{F_0^{D\pi}(m_K^2)} \cdot \frac{m_D^2 - m_K^2}{m_D^2 - m_\pi^2}$	0.79
$K^0\rho^+$ vs $\bar{K}^0\rho^+$	$1 + \frac{a_1}{a_2} \cdot \frac{f_\rho}{f_K} \cdot \frac{F_1^{DK}(m_\rho^2)}{A_0^{D\rho}(m_K^2)}$	2.7
$K^0a_1^+$ vs $\bar{K}^0a_1^+$	$1 + \frac{a_1}{a_2} \cdot \frac{f_{a_1}}{f_K} \cdot \frac{F_1^{DK}(m_{a_1}^2)}{A_0^{Da_1}(m_K^2)}$	3.9
$K^{*0}\pi^+$ vs $\bar{K}^{*0}\pi^+$	$1 + \frac{a_1}{a_2} \cdot \frac{f_\pi}{f_{K^*}} \cdot \frac{A_0^{DK^*}(m_\pi^2)}{F_1^{D\pi}(m_{K^*}^2)}$	0.54
D_s^+ decays	Expression of R_s	Value of $\|R_s\|$
K^0K^+ vs $\bar{K}^0K^+$	$1 + \frac{a_1}{a_2}$	1.2
K^0K^{*+} vs $\bar{K}^0K^{*+}$	$1 + \frac{a_1}{a_2} \cdot \frac{f_{K^*}}{f_K} \cdot \frac{F_1^{D_sK}(m_{K^*}^2)}{A_0^{D_sK^*}(m_K^2)}$	2.5
$K^{*0}K^+$ vs $\bar{K}^{*0}K^+$	$1 + \frac{a_1}{a_2} \cdot \frac{f_K}{f_{K^*}} \cdot \frac{A_0^{D_sK^*}(m_K^2)}{F_1^{D_sK}(m_{K^*}^2)}$	0.36

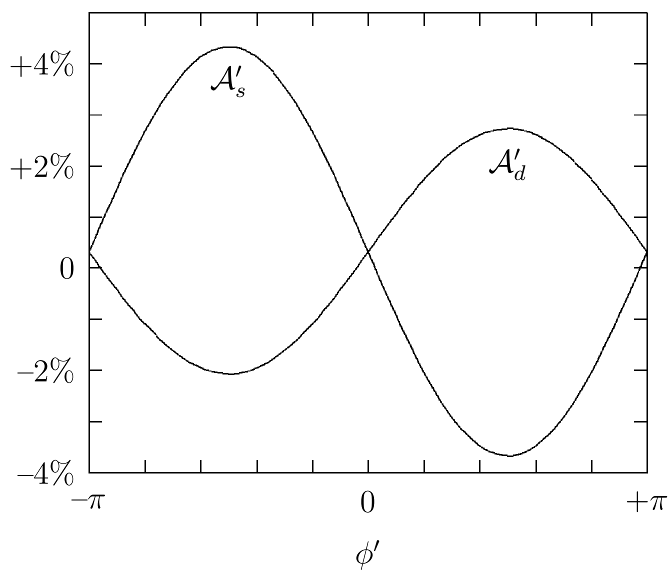

Figure 3: Illustrative plot for CP asymmetries $\mathcal{A}'_d$ and $\mathcal{A}'_s$ changing with the weak phase ϕ', where $r' = 0.04$, $R'_d \sin\delta'_d = 0.3$ and $R'_s \sin\delta'_s = -0.5$ have typically been taken.